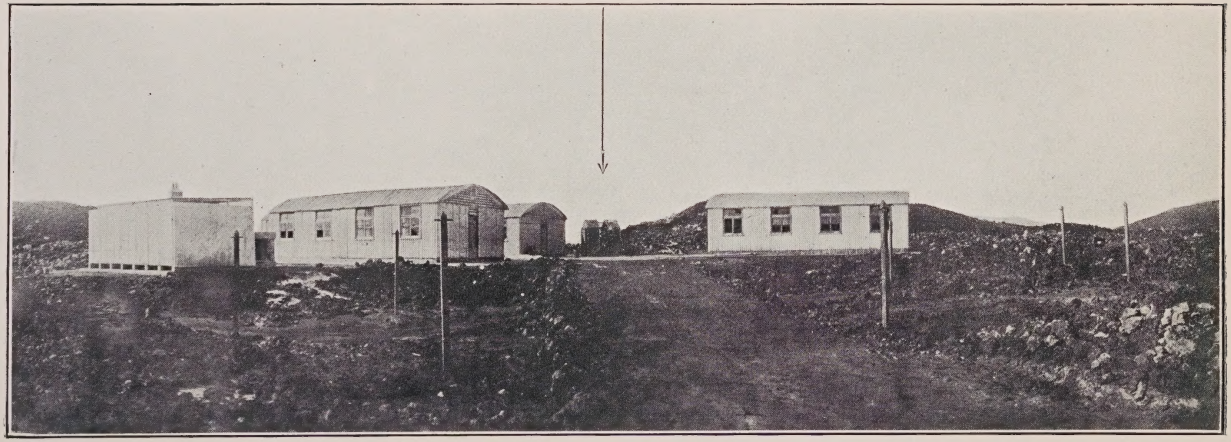
THE PORTABLE TRANSIT INSTRUMENT.



[Frontispiece.

NEW KRU TOWN, ASCENSION ISLAND, SHEWING POSITION OF TRANSIT HUT, 1908.

Astron.

NOTES ON THE USE

OF THE

Portable Reversible

Transit Instrument

AND THE METHOD OF CALCULATION

OF THE OBSERVATIONS.

BY

C. E. MONRO,

Captain, R.N., F.R G.S. F.R.A.S.

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PREFACE.

These notes on the Transit Instrument were mostly made at the Royal Observatory, Greenwich, in the autumn of 1907, where I had been sent to learn the use of the instrument, and ascertain personal equation compared with the Standard Observer at the Transit Circle in connection with the longitude determination Greenwich —Ascension—Cape which was carried out in February of the following year. Some additions to them have been made after the experience of setting up and working with the instrument at Ascension.

Mr. H. P. Hollis, of the Royal Observatory, to whom I am much indebted for what I know of the transit instrument, kindly read through my notes, making valuable suggestions for their improvement, and also supplied me with much explanatory material of which I have made liberal use in the following pages.

The instrument here described is one of five that were purchased for the Transit of Venus Expedition, 1874. It has since then been considerably altered and improved for use in various longitude determinations.

The notes are intended purely for the use of beginners by one of whom and for whom they were originally set down, and who found them invaluable when landed without the friendly aid of mentor to fall back upon. It is of course almost imperative to have had some personal instruction in the use of the instrument before attempting to work with it, and these notes do not pretend to be an exhaustive treatise on the instrument.

C. E. M.

Board of Trade, S.W.

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CHAPTER I.

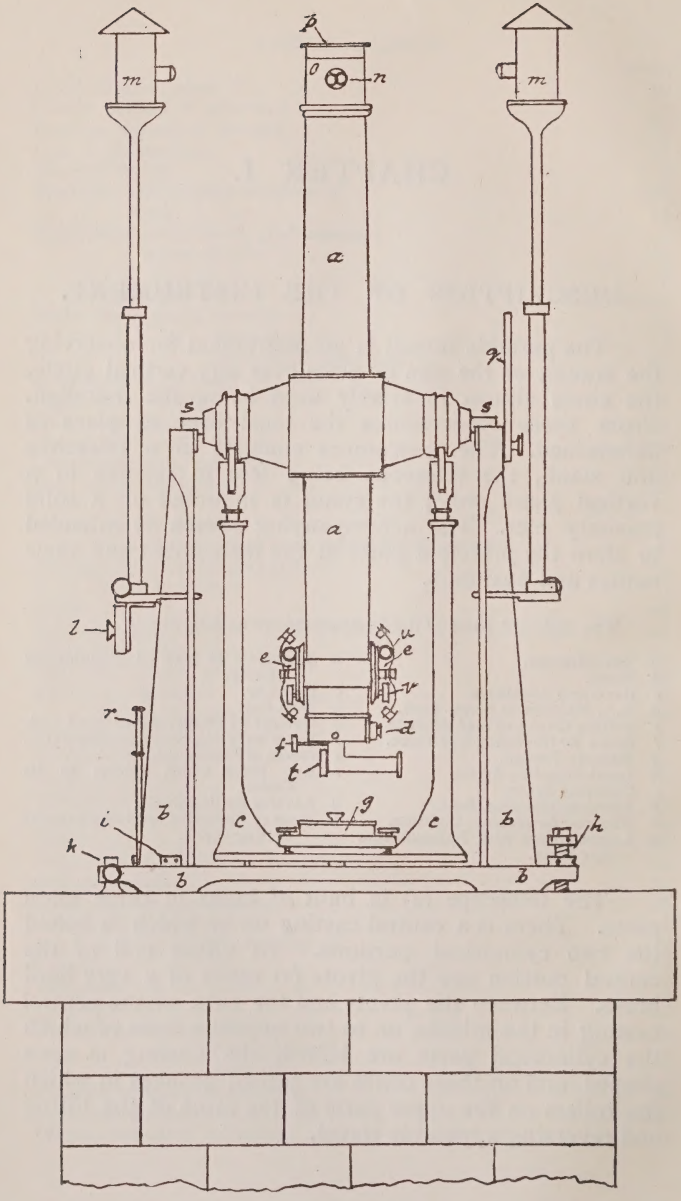
DESCRIPTION OF THE INSTRUMENT.

The portable transit is an instrument for observing the transit of the sun or stars over any vertical circle, the circle almost invariably used being the meridian. From these observations the local time at place is determined. The instrument consists of a telescope and stand, the telescope being free to revolve in a vertical plane only; the stand is mounted on a solid masonry pier. The accompanying sketch is intended to show the principal parts of the instrument and their names and positions.

The different parts of the Instrument are as follows :—

a The telescope.
b Stand.
c Reversing Apparatus.
d R.A. Micrometer Screw head.
e Setting Circles to read Altitude.
f Screw for traversing Eye Piece.
g Mercury Trough.
h Level Adjusting Screw.
i Clamping Screw.
k Azimuth Adjusting Bolt.
l Rheostat for Internal Lighting.
m Lamps for use with Bohnenberger Eye Piece.
n Terminals of Internal Illuminating Lamp.
o Dew Cap.
p Dust Cap.
q Upright for steadying Striding Level.
r Lever for lifting Reversing Apparatus.
s Pivots of Instrument.
t Eye Piece which rotates in its Collar.
u Level of Setting Circle.
v Head of Pinion for revolving plate of Setting Circle.

The telescope (*a*) is built of brass in three main parts. There is a central casting on to which is bolted the two cylindrical portions. At either end of the central portion are the pivots (*s*) made of a very hard brass. Between the pivots and the cube of the central casting in the middle, on to two opposite faces of which the cylindrical parts are bolted, the casting is cone shaped, and on these cones are turned grooves in which the rollers on the upper parts of the arms of the lifting and reversing apparatus travel.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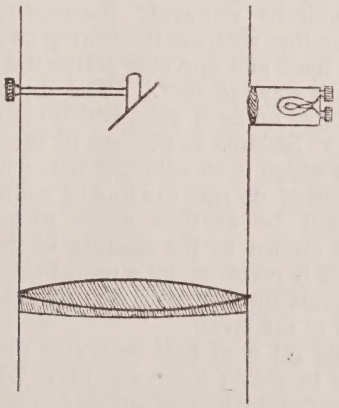
Into the outer end of one of the cylindrical portions is fitted the object glass, and outside this again is screwed on a further cylindrical piece for the protection of the object glass, and called the dew cap (*o*). In this dew cap is placed the electric lamp and reflector by means of which the field is illuminated, enabling the observer to see the wires over which the transits are recorded at night. This will be referred to as the internal illumination. This method of illumination, devised by Sir W. H. M. Christie, consists of a small lamp placed in a short tube having a condensing lens at its end. This tube is then fastened to the outer side of the dew cap so that the rays from the lamp fall on a surface of finely ground opal glass held in front of the centre of the object glass by means of three watch spring stays. The opal glass is placed at an angle to scatter the rays from the lamp directly into the telescope.



At the outer end of the other cylinder is the eyepiece (diagonal) (*t*). This rotates in its collar which screws into a plate. This plate to which the eyepiece is thus fastened is fitted to move in a direction parallel to the axis of rotation of the instrument, and is moved by a coarse pitched screw (*f*). The *apparent* effect of this is, when looking in to the eyepiece, to move the wires across the field of view.

Within this cylinder, near the eyepiece, is the diaphragm on which are placed the wires. These consist of nine spider webs, placed at right angles to the line of axis of rotation of the instrument, and arranged so that the intervals between consecutive wires of the first and last four are equal, that between the 4th and 5th and between the 5th and 6th wires equal to each other but greater than the other intervals. Besides these nine wires there are two others at right angles to them and approximately on either side of the centre of the field (see cut on page 25). The diaphragm is capable of movement in a line parallel to the axis of rotation of the instrument, and this movement is made by means of a micrometer screw (*d*) graduated on its head. This is known as the R. A.* micrometer screw. A cap fits over the head of this screw, to prevent it being moved by accident, a small portion of the cap being cut away to enable the setting to be seen without its removal. Secured to the instrument, one on either side, are the setting circles (*e*). Each consists of a fixed and movable plate, the former being graduated both ways to 180°. The movable plate has two verniers, one on each side, which are read by small microscopes. Secured to the face of the movable plate is a level (*u*), which is so adjusted that when the bubble is in the centre of its run the line of collimation of the instrument will be at that angle to the horizontal plane that is shown by the reading of the circle. The movable circle is revolved by a milled-headed cog wheel (*v*) which stands up from the face of the circle on the side opposite to the level.

The stand (*b*) is of cast-iron, and the uprights are shaped so as to obtain great rigidity. The upper parts of these uprights have semi-circular grooves into which are fitted the hard brass bearings for the pivots of the instrument. Too much care cannot be taken of these pivots and bearings to prevent the slightest grit from getting on them, and metal covers are fitted over them which should be always kept on when the instrument is not in use to prevent dust settling on to them.

At one end of the base of the stand is the level adjusting screw (*h*) by means of which that end of the

* Right Ascension.

stand can be raised or lowered. When in adjustment, it is secured by a check nut. This levelling screw has a cone-shaped end, which rests into a similarly shaped recess in the head of the lewis, which is let into the stone slab on which the instrument is mounted. On the opposite side of the base of the stand is a projection in which is a long shaped slot. Into each side of this slot projects the end of an adjusting screw. The head of the lewis (*k*) projects up through the slot, and the adjusting screws are turned to press up against this head on each side. By unscrewing one of these and screwing up the other, it is evident the instrument can be moved in azimuth as required.

On each side of the upright nearest to the azimuth adjusting lewis is a clamping screw (*i*). These screw into lewises let into the stone just as the other two. The holes in the stand through which they pass are elongated to allow of a small amount of motion being given to the stand in azimuth.

The reversing apparatus consists of two upright arms on a centrally pivoted base (*c*). This is fitted in the centre of the base of the stand. Into the upper end of each of the arms is fitted a metal casting carrying two rollers. The whole is capable of being lifted about 1½ inches by means of the lever (*r*). The metal rollers are quite free when the apparatus is down, but when it is lifted they engage in the grooves on the coned arms of the instrument, and the whole is raised to such a height that the pivots are free to pass over the upper faces of the upright arms of the stand. On the under side of the base is a projecting stud which is so placed that when the instrument, having been revolved, is in such a position that the pivots are truly over the bearings it frees from a spring (not shown in sketch) fixed on the upper sides of the stand and can then engage in a hole in the stand. Unless the instrument is so placed that the pivots are truly over the bearings this stud would rest on the stand and so prevent the lowering of the reversing apparatus and the consequent damage to the pivots.

Standing on the base of the reversing apparatus is the mercury trough (*g*) for use in the Nadir observa-

tions. It is made of copper of about 6 inches diameter, and slightly concave in shape as a saucer. To get the trough ready for use the surface of the copper is well amalgamated with mercury and with this amalgam a very thin layer of mercury is used. With an ordinary mercury bath the tremors set up by traffic or other causes have been found to be so lasting that under certain conditions observations with it are almost impossible. The advantage of the amalgamated trough is that if any vibration is given to the mercury, it will very readily come to rest. The trough rests on a stand fitted with levelling screws, and has a cover to keep the dust from it.

On either side of the instrument and level with the upper end of the tube, when the telescope is in a vertical position, are the lamps (*m*) for use with the Bohnenberger eye piece. They are usually here referred to as the side lamps or lights. The light used is a small electric lamp, the rays from which are, of course, screened, except where they pass through the small tube at the side. The outer end of this tube is fitted with a condensing lens. These lamps are placed on rests fitted on the ends of telescopic rods, so that they may be adjusted carefully for height to allow the light from them to fall truly into the side of the Bohnenberger eye piece. The lower ends of the rods are clamped on to a bracket fitted to the outer side of the uprights of the stand.

Under this bracket (on the left hand side in the sketch) will be seen the rheostat (*l*) the wires from which lead to the terminals (*n*) of the internal lighting lamp. These wires are fairly long, and are usually twisted, to keep them out of the way, round the tube of the telescope in such a direction that as the instrument is reversed they will unwind. The rheostat is placed conveniently so that the amount of light in the field of the telescope may be varied while actually observing; it is better, however, to keep the illumination, as far as possible, constant. At the top of the right hand upright of the stand, in the sketch, is screwed a steadying piece (*g*). This is slotted down from its upper end for about a third of its length, and when the striding level is placed on the instrument, a stud which projects from either end

of the level engages in this slot, and though it must not touch either side of it when in ordinary use, should the level be accidentally pushed, this slot will hold it and prevent it falling. The slot too is convenient when placing the level on the pivots to guide it into place.

The Bohnenberger eyepiece, mentioned above, is somewhat similar in shape to the ordinary eyepiece, and when taking the Nadir observations (described further on) it is screwed on in its place. It is fitted inside with a reflector, so arranged that the light from the side lamps is thrown down the tube, and so illuminates the wires that both they and the reflections of them in the mercury trough can be seen when looking into the eyepiece.

CHAPTER II.

THE PRINCIPLE OF THE REVERSIBLE TRANSIT.*

When a carpenter or engineer wishes to test the accuracy of his set-square he applies it to the straight edge of a board and rules a pencil line along its edge. He then turns it over and bringing the edge to the same point at the edge of the board rules another line. If these two lines exactly coincide he knows his instrument is true, but if they do not he must adjust his square so that the line ruled will come midway between them. The principle of this method is often made use of in astronomical measurements.

The reversible transit may be regarded as a set-square with the line of collimation as the fiducial edge. The line of collimation is the line of sight of the telescope and is actually the line which joins the centre of the object glass to a point on the middle thread of the system of nine spider webs, which make up the reticle before described, when properly adjusted. The purpose of observations with this instrument is to find the time by the clock when a star is seen on this line, and its adjustment should be such that it should indicate the same point in the heavens before and after the telescope is reversed in its bearings, or, in other words, the result should be the same whichever pivot of the telescope rests in the western (say) bearing.

There are methods for finding the "collimation" or position of the reticle of wires which will realize this approximately, but it is sometimes found difficult in

* The ideas embodied in this and the following chapter are in great part due to Mr. H. P. Hollis.

practice to find a position which will ensure *precise* equality of results in the two positions of the instrument. This may be due to imperfections in the form of pivots and bearings or from some cause not readily apparent, but, following the analogy of the carpenter and the set square, the principle of the reversible transit is to observe stars to find the clock error in both positions of the instrument—reversing it in its bearings, and making the operations in the two positions as symmetrical as possible—and to take the mean of the results. In the following paragraphs some points in the geometry of this matter are considered.

Let us consider what line in the transit instrument corresponds to the edge of the set-square which is placed against the edge of the board. Supposing for the moment that the telescope remains pointing in one position all the time, say to the zenith, and that the pivots rest on two plane surfaces as bearings, the line joining the points of the pivots which are in contact with the planes will be that line. Again, if the pivots are exactly circular and equal, and if they turn in exactly circular bearings which have radii equal to those of the pivots, the line which joins the centres of the circular ends of the pivots will occupy the same position before and after reversal, and thus corresponds to the line of the set square we are imagining. This is the perfect case because this line remains in the same position in space when the telescope is reversed end for end and also while it is turned in its bearings and the line at right angles to it—the line of collimation—describes a great circle. Now supposing, as an extreme case of imperfection, the pivots to be unequal and the bearings also not equal in radius to the pivots nor to one another, still there will be some one line in the whole substance of the axis which occupies the same direction in space before and after reversal, this line being only altered end for end, so that if it were possible to use the instrument always pointing to the zenith these imperfections of pivots and bearings would not matter. For by finding the level error of the telescope in the east and west positions and taking the mean we have the level of this invariably placed line, and in finding the

collimation by reversal, which is what we essentially do when we find clock error by observing stars in both positions of the instrument, we define a line at right angles to this invariable line, so that we have the transit instrument in its final simplicity—a levelled line with another at right angles to it. Obviously it is not possible to observe stars only in the zenith, nor is it possible, for certain practical reasons, to find the level when the telescope is turned directly upward, but this hypothetical case is set down as embodying the principle of reversal.

The adjusting screws of the instrument are for the purpose of placing it so that the great circle described by the line of collimation shall be as near as possible coincident with the meridian. (An error in collimation will make this circle a small circle instead of a great circle.) The observations of polar stars and with the level show how far the coincidence with the meridian is realised. Since the object of the transit-instrument is to ascertain the time when stars cross the actual true meridian of the place, it is necessary to apply corrections to the time observed when objects cross the meridian marked out by the imperfectly placed instrument. The computation and application of corrections for such errors of level and azimuth are described in subsequent chapters.

It is necessary that the spider webs (wires) over which the time of transit is observed should be exactly in the focus both of the object glass and of the eye-piece. The operation of placing the wires in this position should be done before any series of observations is begun, and when done the wires should remain permanently in that position. A method of doing this is to set the telescope on to a polar star of about the 5th magnitude, and having carefully adjusted the eye-piece so that the wires are in focus, the frame carrying the wires and eyepiece must be moved by the screws provided for the purpose until the star is also in focus. The wire frame must, as well, be set so that the vertical wires are at right angles to the direction of the diurnal motion of the stars, or in other words are in the direction of the vertical circle swept by the rotation of the instrument. This may be done by means of the Bohnenberger eye-piece. The central wire

and its reflected inverted image must be made to coincide when the comb and its image are on opposite sides of the field, and again when they are on the same side. The readings of the micrometer screw for the two coincidences should be the same. It will be realized that the wires are seen under various conditions. They are seen as dark lines on the bright background of the field of view illuminated by day light, by artificial light from outside or inside the telescope when using the ordinary eye-piece, or by a totally different method when using the Bohnenberger eye-piece. In all cases they are shadows, and there is the possibility that these shadows may take up a different position in the varying conditions. Formerly a usual method of lighting the instrument was to fit an annular or small central reflector in the central cube of the instrument, and this reflected the light from a lamp placed opposite one end of the axis of the telescope which was perforated. To obviate some of the above difficulties an alternative method has been proposed by Sir W. H. M. Christie (see page 7) in which a light scattering surface placed outside the object glass throws light through that lens into the tube. This method, however, does not overcome any of the difficulties due to the difference of lighting when the Bohnenberger eye-piece is used. It is possible that a difference of focus of the eye-piece may displace the apparent position of the wires, but this is a recondite subject and no proved conclusion has yet been arrived at. There is no doubt, however, that the greatest care should be taken in placing the wires in the exact focus of the objective, and in adjusting the eye-piece to have the wires in focus also.

As already stated, if the trunnions or pivots on which the telescope rests are perfectly equal cylinders having the same axis and turn in bearings in which they fit perfectly, the whole instrument will revolve about the geometrical line which is the axis of those pivots. This axis will retain its position in space in all positions of the instrument, even when reversed in its bearings. Under these conditions the fiducial line defined by the central web (line of collimation) which is at right angles to this axis will sweep out a great circle as the telescope is rotated. It is scarcely possible that these ideal

conditions of workmanship can be fulfilled, and some discordance on this account may be expected.

Bearings are of two kinds. They may consist of two planes at right angles, V shaped bearings (Fig. 1). This form is theoretically good, since the purpose is to make the pivot rest on geometrical lines ; but the purpose is rarely or never fulfilled in practice owing to wear of the surfaces. The other form is known as the segmental bearing, where the pivot rests on two segments of a circle of the same diameter as itself (Fig. 2). But here it is not

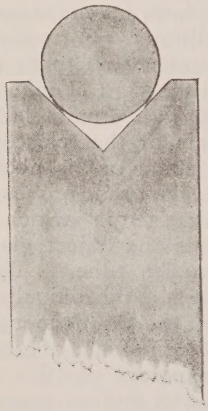


Fig. 1.

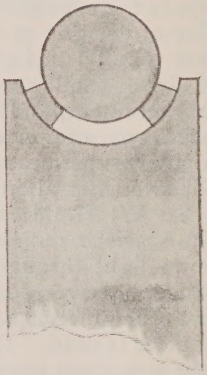


Fig. 2.

possible to ensure exact equality in the diameters. In any case it is not well to have the segments parts of a circle of larger diameter than the pivots. In practice the pivots generally fit themselves to a bearing by wear, so that it is as well that they should at first rest rather on the top edges of the segments than on the lower.

The pivots and bearings should be kept scrupulously clean, and watch should be kept on their wearing. No oil should be put on them, especially in dusty and windy localities, for in this case the combined oil and dust will make a very effective grinding paste.

There is a form of bearing in which the adjustment for azimuth is made by a small horizontal movement of

one bearing relative to the stand, and the adjustment for level by a vertical movement of the other bearing. An objection to this arrangement is that after such adjustment the pivots of the telescope take up a position on the bearings different to that which they previously occupied. In the case of the instrument shown in the diagram the adjustments for level and azimuth are made as previously described by moving the whole stand, which seems to be a more satisfactory method.

The eye piece used for observation of stars is usually of the diagonal reflecting type for convenience in observing. When in use it is turned into a position at right angles to the position shown in the diagram. This turning motion is possible because the short tube is attached to the telescope by means of a collar which screws into the telescope, the eye piece tube fitting fairly loosely in the collar. It should not be too loose so that it "hangs" for in this case the focus may require adjustment after reversal of the instrument from East to West position and such adjustment is inadvisable.

The whole eye piece, as before explained, can be traversed across the aperture in the plate on which it is mounted so as to bring any of the wires of the system into the middle of the field. In observing transits it is advisable to set it so that the middle wire is in the centre of the field and to observe the transit on all the wires with this setting, and not to move it during the transit.

CHAPTER III.

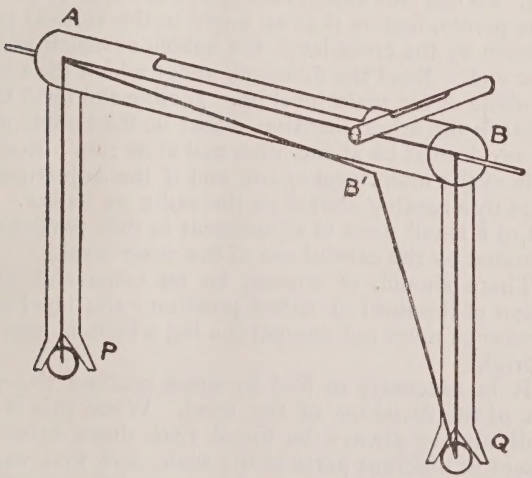
THE LEVEL.

The most important adjunct to the transit instrument is the level, This consists of a cylindrical glass tube, the interior of which has been accurately worked to the shape that would result from the rotation of a small arc of a large radius about its chord. The tube is nearly filled with a mobile fluid, leaving a space occupied by a bubble of air which necessarily occupies the highest point in the tube. The tube is mounted in a metal case, having a leg at each end shaped to a V shaped foot, which rests on the pivot of the transit instrument. The upper surface of the glass tube thus mounted is graduated by marks cut equidistantly along its length.

The practical use of the level may be explained as follows. The graduations on the tube are numbered from one end to the other. Now, if we place the level in position on the pivots of the instrument, and note the divisions and parts that coincide with the two ends of the bubble, and take the mean of these, we may call this the bubble reading. When the instrument is level, this bubble reading is called the zero of the level, call this d. Now suppose the transit instrument is not level, but that that side is highest over which the larger numbered graduations are, we shall find then that the bubble reading will be some quantity greater than d, say $d + \beta$. If now we reverse the level on the transit instrument, the smaller numbered divisions will be over the higher side, and, assuming the divisions to be of equal value, the bubble reading will be $d - \beta$. Half the difference of these two readings is β, which represents, in divisions of the bubble, the angle from the true horizontal of the pivots of the instrument—the level error of the instrument—which we want to find.

The level is provided with a cross-level, a short level at right angles to the axis of the main level, placed at one end, and when the instrument is placed on the pivots of the transit instrument the bubble of this cross-level must be in the centre of its run in all cases. This will ensure the main level being placed symmetrically with respect to the vertical plane in both positions, cross-level east and cross-level west. The careful use of the cross-level is important for the following reason.

In a perfectly adjusted level the true axis of the glass tube and the central lines of the legs, that is the



lines joining the axis of the pivots of the transit instrument to the axis of the bubble, should be in one plane. This is represented in the diagram where A B, A P and B Q are in one plane. That plane should be vertical, though the exactitude of this is not absolutely essential provided that the legs are in one plane. Supposing that B Q be not in the same plane as A B and A P but in the position B′ Q, it is evident that A B′, the level of which is being measured, is not on the same level as A B, the level of which is really wanted.

If we now reverse the level on the pivots of the instrument and place it so that the leg B′ Q is truly vertical it is evident that the bubble will again be inclined down towards the same side as before and the error will be repeated. If, on the other hand, the leg A P be again made vertical when in its new position the bubble will slope towards the other side, and the mean of the determinations in the two positions will give us the quantity we require.

In many levels there is a means of adjusting the glass tube in the metal case so as to alter the position of the point A or B to make A P and B Q lie in the same plane. To test this adjustment, place the level in position on the pivots, incline it at an angle to the vertical plane, as shown by the cross-level, the bubble of which will run to one end. Read the divisions under which the ends of the bubble of the main level lie. Incline the level to the vertical in the other direction,—that is, the bubble of the cross-level must be at the other end of its run. Read the bubble of the main level again, and if the adjustment is perfect this reading should be the same as before. The effect of a small want of adjustment in this particular is eliminated by the careful use of the cross-level.

There should, of course, be no constraint of the position of the level in either position ; the level guard for instance must not compel the leg which is near it to be upright

It is necessary to find by some method the value in arc of the divisions of the level. When this is done it will almost always be found that these values are different at different parts of the scale, and that even at the same parts of the scale the values differ at different temperatures. To eliminate to a great extent difficulties from these causes a level has been devised (see Monthly notices R.A.S., vol. LII., page 52) which is in effect a combination of level and level prover. In this the glass tube rests in a metal case of which one end is pivoted and the other end rests on a lever near to its fulcrum. The end of this lever is raised or lowered by means of a micrometer screw with a graduated head.

On placing the level in position on the pivots of the transit instrument the screw is turned until the bubble

takes up a convenient position on the scale. After reversing the level the screw is turned so that the bubble again takes up the same position and the difference of level in the two positions, or the level of the axis of the instrument which is half the difference, is measured in terms of the revolution of the screw. It is an instrument of this sort the use of which is described in these pages.

CHAPTER IV.

ERECTING THE INSTRUMENT.

Having selected a suitable position, first obtain an approximate meridian by true bearing with theodolite or even shadow from sun at apparent noon, and fix up a mark as far off as possible (over ½ a mile to 1 mile or more) in that meridian*. The instrument must be mounted on as rigid a pier as possible. The following dimensions are recommended:—

Concrete foundation 4 feet cube, the top to be flush with the ground, the sides being oriented. When the foundation is well set a brick pier to be built in the centre of it about 2 feet by 1 foot, and 1 foot 3 inches high, the longest side to lie east and west.

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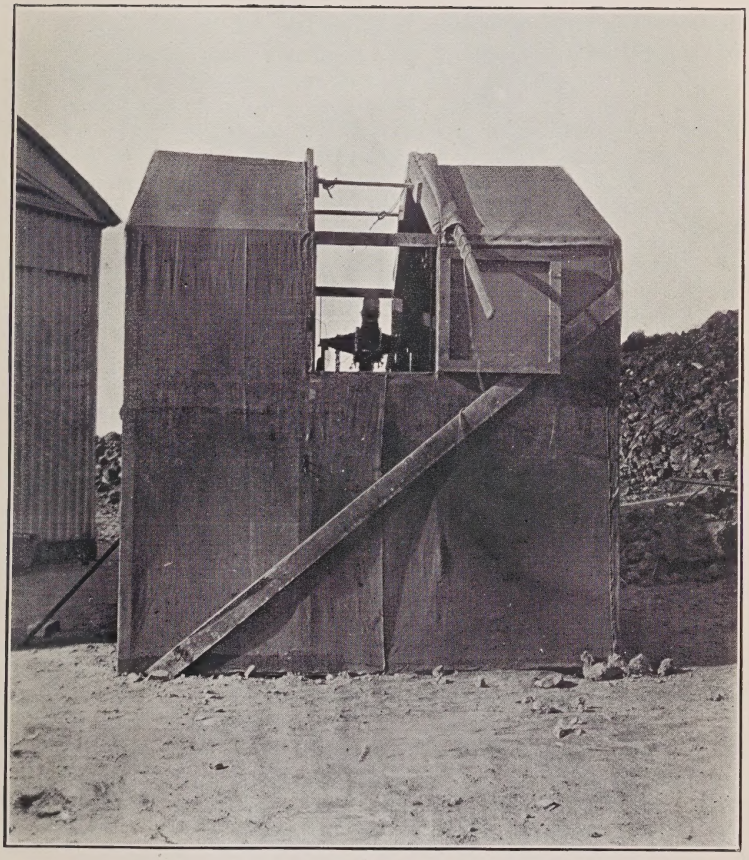
* The method adopted at Ascension was as follows. A meridian mark was constructed of planks about 6 inches wide, in the shape of an A, with a strut at the back to keep it upright. The cross piece was painted white and across the middle of it a vertical black line, about ⅛ of an inch wide, was painted. This mark was placed on a ridge on the sky line as far off as possible and due south from the instrument, a compass being used for this purpose.

A theodolite was then erected over, as exactly as possible, the position to be occupied by the centre of the pier.

Using a distant object as zero, observations of the sun, when at a low altitude, were made in the four quadrants formed by the cross wires of the theodolite, in each case with the vertical and horizontal wire tangential to the sun's limb. At each observation the altitute was read off from the vertical arc and the time also taken. As is readily seen the mean of these observations corresponds with that of the sun's centre at the cross of the wires.

With these observations the true bearing of the distant object was calculated. The angle between this bearing and the south meridian was set on the instrument, still keeping the same distant object as zero. The meridian mark was then moved so that the black line on the cross piece was cut by the vertical wire.

This was found to be but little out of truth when the azimuth error of the transit instrument had been properly ascertained. The mark was then accurately adjusted and permanently secured.



To face p. 22.] [Photograph by Lieut. C. M. Gibson, R.N.

TRANSIT HUT AT ASCENSION, 1908.

On the brick pier should be cemented a stone, smooth on top, of 2 feet 8 inches in length, 1 foot 6 inches in width, and 6 inches thick. A good substitute for the stone is a block of concrete cast in a mould on the top of the bricks, and it has this advantage, that the holes for bedding in the lewises of the instrument can be made in it while it is wet, whereas they must be cut out of stone.

The lewises are the iron fittings, cemented into the stone, by which the instrument is secured to the stone and adjusted on it for level and azimuth. They are four in number (see page 6). That for level adjusting should be on the east side and that for azimuth adjusting on the west side, the two for the clamping screws are then on the north and south sides, one on each side.

When making the holes for the lewises it is best to make a rough wooden template of the bottom of the stand of the instrument with holes bored in it to correspond with the holes in the stand. This can be placed on the stone and the positions marked direct. It is easier to handle than the stand, which is heavy and should not be given the chance of getting knocked about. Place the lewises in these holes in the stone, and, with the bolts that screw into them passing through the holes in the template, run in cement or plaster of paris, keeping the template in position until the cement is beginning to harden, when replace the template by the stand itself, ship the telescope and move the whole as required to get the central wire on to the meridian mark with the lewises fairly central in the slotted holes to which they correspond. Fill up the holes with the cement flush with the top of the stone, and leave the whole to dry and set thoroughly hard; if cement, for about two days, but if plaster of paris, a few hours would be sufficient.

Adjust the instrument for level, using the striding level.

As soon as possible get observations for finding the azimuth error, *i.e.*, observations for level and for "n" by polar and clock stars. The instrument can then be adjusted by the use of the screw on the west of the stand,

as described on page 46. When this is done, set taut the clamping screws, and the instrument will be ready for use.

A hut should be erected over the instrument to keep it from rain, &c., and also to keep the sun off it during the day. The floor of this hut should be laid with wood so arranged that no part of it touches or rests on the foundation of the pier, and should be well clear of the pier—say three inches all round it. It is very convenient, as well, to erect a wooden framework round the pier, leaving a space of about 3 inches between it and the pier. This prevents one's knees or feet touching the pier while observing, and is also useful for attaching the switches of the electric light to for the lamps of the instrument.

Separate batteries should be used for the lights for the Bohnenberger eyepiece and for the lamp outside the object glass used for the internal lighting. The cell for the "tapper" circuit is, of course, different from these again, and forms part of the chronograph outfit, described later.

Star Catalogue.—This should be made out beforehand, and should include all the stars that may be used for the observations which will pass the meridian in the period during which it is intended to observe. They should be arranged according to their right ascensions, and columns filled in showing the polar distance and altitude of each one. They will be selected usually from the principal Ephemerides that are available, which should include at least the Nautical Almanac, the Connaissance des Temps, and the Berlinische Jahrbuch. Against each star will be noted the Ephemeris from which it is taken—NA, CT, or BJ, &c. In selecting the stars for the catalogue, which will, of course, be mainly equatorial or "clock" stars, a proportion of polar stars should be taken interspersed amongst them, and the greater declination these latter have, the better. With an instrument of the size described in these pages a star of the 7th magnitude is about the smallest that can be observed and then only on a really clear night. Under ordinary circumstances those of the 3rd and 4th magnitude will be found the most suitable.

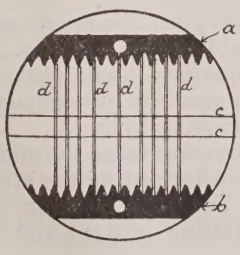
CHAPTER V.

METHOD OF OBSERVATION.

The following paragraphs show the actual procedure of a night's work.

It may be assumed that local time is known approximately. Compare chronometer with this and note error on local S.T. so as to use chronometer to see what stars are about to pass the meridian.

Take a Nadir Observation. Remove pivot covers and dust-cap from object-glass of instrument and also the cover of the mercury trough and see the trough is level and mercury clean. Re-place the diagonal eye-piece by the Bohnenberger eye-piece. Switch on both lights which are placed on the rods on each side of the stand; both lights should always be used to avoid unequal heating. Invert the telescope, and looking through the eye-piece move it so that the wires can be seen, then tap it gently until the comb and reflected image of the comb are on opposite sides of the field and the cross wires and their reflected images are covering each other.



a—Image of Comb.
b—Reflected Image of Comb.
c—Horizontal Wires, covering.
d—Vertical Wires, nearly touching.

Take off the cover of the R.A. micrometer screw-head and move it until the centre wire and its reflected image are just touching. Read the micrometer screw; then turn the screw until they touch on the other side and read the screw again. Repeat this. Then turn the eye-piece round through 180 degrees and repeat the operation. Next reverse the instrument. Turn over the lifting lever at the side of the stand, which raises the instrument sufficiently for the pivots to clear the bearings, then push round the carrier of the reversing apparatus until the pivots plumb the bearings on the opposite sides and then lower again by turning the lifting lever to its original position. After reversing revolve the instrument on its pivots to see that it works freely and is not "bound" by the carrier supports. Then repeat the whole of the above.

NOTE.—The position of the instrument is noted East or West according as the micrometer screw head on the eye-piece is on the east or west side. (It is called the R.A. Micrometer.)

Example of Nadir Observations:—

R.A. Mic. West.		R.A. Mic. East.	
12·045	11·983	11·898	11·908
11·973	12·043	·978	·974
12·042	11·983	·907	·908
11·973	12·044	·980	·974
	8) ·086		8) 7·527
	12·0108		11·9409 mean East.
			12·0108 mean West.
			11·9758 mean Reading.

Before commencing to observe set the micrometer screw for the night to its probable mean reading. If this reading is not known from previous Nadir observations take the mean of the Nadir readings just obtained and use that or the nearest even reading to that.

On the night on which the above was taken the micrometer screw was set to 11·970. After setting the screw carefully put the cover over it and then see, in the aperture in the cover, that the setting is right and has

not been accidentally moved when placing on the cover. In reading the above the decimal places are read on the screw-head, which is divided into 100 parts for this purpose; the whole numbers represent revolutions of the screw and may be read by the comb. The centre tooth gap of the comb has a hole cut out above it and represents the tenth revolution. Each tooth gap represents one revolution, and they can thus be counted from the centre tooth gap.

It is, of course, possible that the instrument may not be fitted with a R.A. Micrometer screw. In this case the central wire must be set for collimation as closely as possible by means of the diaphragm adjusting screws, and it is then imperative that stars are observed both East and West and the mean of the resultant clock errors taken.

Throughout any one operation with the Bohnenberger eye-piece the mirror and adjustment of the focus should remain unaltered, the adjustment of the lamps might be varied during a series of several nights to avoid a possible systematic error.

Observations of Stars.—Next see, by reference to the catalogue, what star is about to cross the meridian. Replace the diagonal eye-piece and adjust it for focus, if necessary, at the beginning of a night's work, and keep it at that throughout the night.* See that there is no excessive "hang" of the diagonal eye-piece owing to looseness of the eye-piece slide. This dfficulty may be got over by using an elastic band to attach it to a projecting screw on the telescope tube. Switch off the side lights and switch on the light for internal illumination. Put the altitude of the star on the circle on the right hand side of the instrument, and cant the instrument until the bubble of the altitude circle is in the middle of its run. Now look through the eye-piece, and by turning the small screw on the opposite side to the micrometer screw, move the eyepiece so that the wires are on the West side of

* It may appear at some moments during a night's observations that the eye-piece requires refocussing. This is probably due to some temporary change in the observer's eye, which will become restored to its normal condition after a short interval. It is better, therefore, to resist the temptation to alter the focus adjustment of the eye-piece.

the field. About a minute (for a clock star) before the time of transit the star wlll be seen in the field. Tap the telescope, so as to bring the star between the two horizontal wires. Move back the eyepiece gradually, keeping the star in the field, until the wires are in the centre of the field, and then wait for the star to cross the wires. When nearing the first wire press the "tapper" key 5 or 6 time in quick succession.* When it arrives at the first wire, press, and press for each successive wire. When finished, "rattle" again.

It is generally agreed amongst transit observers that there are two distinct methods of chronographically registering transits. In one the observer watches the star as it comes up to the wire, and is bisected or covered by it, then, and not till then, does he press the key.

In the other method, known popularly as "shooting the flying bird," the observer anticipates the bisection or covering of the star by the wire, and presses the key early by such an interval that his judgment tells him will cause contact to be made exactly when the star is under the wire.

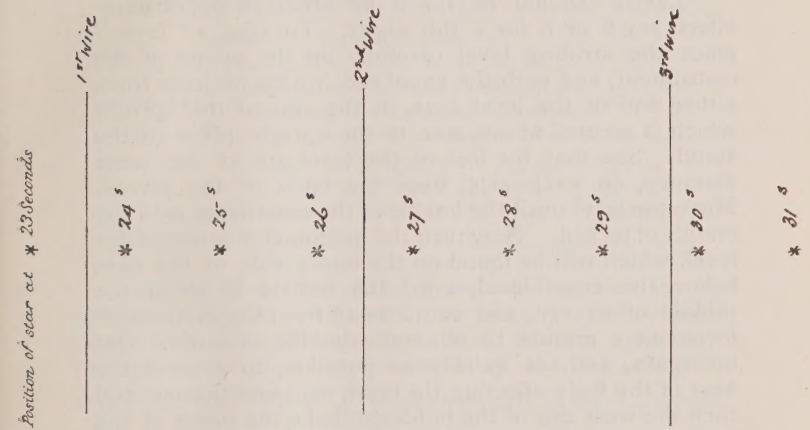
It seems likely that an observer who practises the first method would record transits late relative to the one who adopted the second method, and this is found to be the case. It is considerably a matter of opinion which is the better method of the two, but it is of course absolutely important that having adopted one method, that method must be adhered to, or the results will show a hopeless irregularity. A transit observer, while recording a transit, should endeavour to convert himself as much as possible into a machine.

Eye and Ear Method.—Should the observer not be fortunate enough to possess a chronograph with which to record his observations, he must resort to what is known as the Eye and Ear Method.

The best way to do this is to listen to the beats of the clock or chronometer, and note the position of the star, with reference to the wire over which the transit is

* This pressing the key several times quickly is known as "rattle." Its object is to indicate clearly on the chronograph tape where the observations of the star begin and end.

being recorded, at the exact second before and after crossing the wire thus :—



In the above figure, the positions of the star at the different seconds' beats are shown with reference to the positions of three of the wires of the instrument. In this case, the time of the transit under the first wire would be $23^{s}{\cdot}6$, the second wire, $26^{s}{\cdot}5$, and the third wire, $29^{s}{\cdot}7$.

One advantage in this method is that the interpolation measurement is made mentally by space instead of time, and this is found by the vast majority of observers to be the simpler method of the two.

After a little practice it will be found comparatively easy to estimate very closely by these means the fraction of the second at which the star appeared to be exactly under the wire. This is either written down by the observer or an assistant as convenient.

It need hardly be said that the time of the transits may be taken in a manner similar to that commonly in use for sextant observations where the observer would call "stop" as he observed the transit, and the assistant

would record the time, but this method is not nearly so accurate in itself as that just described, and it duplicates the probable errors due to varying personal equations.

*Levels** should be taken as often as opportunity offers, say 6 or 8 for a full night. To take a "level," place the striding level carefully on the pivots of the instrument, and with the small rod, which projects from either end of the level case, in the slot of the upright which is secured at one side to the upright pillar of the stand. See that the feet of the level are at the same distance, on each side, from the ends of the pivots. Move the level until the bubble of the cross-level is in the middle of its run. Now turn the micrometer screw of the level, which will be found on the under side of the case below the cross level, until the bubble is about the middle of its run, and come away from the instrument for about a minute to allow the bubble to settle. Get up again, and, as quickly as possible, to prevent the heat of the body affecting the level, read first the east and then the west end of the bubble. Take the mean of the readings, and note also in the book "e" or "w," according as the cross-level is on the east or west side. Lift the level off, and replace it in the reversed position, taking the same precautions as before. If with the reading of the screw the same as it was in the first position, the bubble is found to be much out of the middle of its run, move the screw to bring it about central again, but if not, leave the screw at the same reading. Read the bubble as before, *always reading the east end first.*

Take the mean of these bubble readings.

Lift off and reverse as above, so that the level is now in the same position as in the first reading. Now look at the two mean bubble readings obtained, and move the Micrometer screw so that the mean of the first and

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* The level, the use of which is described here, is fitted with a lever and micrometer screw, so that the bubble may be brought at each observation to nearly the same position in the tube. Reference for further information is given on p. 20. Should the level not be fitted with a micrometer screw, the procedure will be similar, but the instruction to turn the micrometer screw must be neglected and the difference of screw readings taken as Nil.

third mean readings will be as near as possible the same as the second mean reading. To increase the mean reading increase the Micrometer reading, and to decrease it, decrease the Micrometer reading.

Example of Level:—

Level. R.A. Mic. East.

Cross-Level.	Micrometer Reading.	E. end of Level.	W. end of Level.	Mean.
e.	18·0	69·5	12·6	41·05
w.	18·0	15·2	72·1	43·65
e.	22·0	73·5	16·5	45·00

In the above the second mean reading was found greater than the first, and therefore for the third observation the Micrometer screw reading was increased so as to make the mean of the 1st and 3rd equal the 2nd. Thus $\begin{matrix}41\cdot05\\45\cdot00\end{matrix}$ mean equals 43·02 ~ 43·65 equals 0·63. The smaller this difference can be reduced to the better. The above would be the procedure in taking the level observation with the amount of level unknown even approximately. Now from the above it is seen that the level error is roughly 2·0 divisions of Micrometer screw, so that when the next level is taken it would be better to observe as follows in order that the three readings of the bubble may be as nearly as possible the same; that is, that the bubble may be situated at the same position in the glass tube, and consequently that the irregularities in the shape and size of the tube will not be introduced.

e. ... 18·0 ... 69·5 ... 12·6 ... 41·05
w. ... 17·0 ... 13·7 ... 70·6 ... 42·15
e. ... 20·0 ... 71·3 ... 14·3 ... 42·80

Directions for deducing the level error from a set of observations such as these are given on page .

Do not hang the striding level in a draught. Keep it always at the same temperature when in use and at other times. Keep away from it as much as possible when observing. Handle it gently and carefully.

The following is the order which should, if possible, be followed in observing for a full night's observations :

1. Nadir Observation.
2. About 4 to 8 stars for clock error, and at least one polar star, *i.e.*, a star within about 10° of the Pole.
3. Reverse instrument.
4. About 8 to 16 stars for clock error, and, if possible, 2 polar stars.
5. Reverse instrument.
6. About 4 to 8 stars for clock error and a polar.
7. A Nadir Observation.

Before removing the cap of micrometer screw for the last Nadir Observation, have another look at the reading to see that it has not accidentally moved. Levels should be taken, so as to have an even number East or West, in the intervals that occur when there are no stars passing, or in cases where stars are temporarily obscured by clouds, &c. They should be taken with the cross-level placed in the order alternately $\begin{matrix} e & w \\ w & e \\ e & w \end{matrix}$ and

It is as well when observing to alternate the position of the instrument on consecutive nights. Thus begin observations with R.A. Mic. East one night, and on the next night with R.A. Mic. West.

The Chronograph is worked by the assistant who should see that it is kept wound up, and this may conveniently be done after each star observed. When the observer sees the star coming near the first wire, he gives the order to start the chronograph, and this should be in time for the "rattle" to be recorded on the tape while running. The name of the star is written on the tape usually just before the first rattle. Other remarks recorded on the tape such as change of observers, reversal of instrument, &c., are often of use for identifying the observations the next day when reading off the tapes.

All chronographs used in connection with a chronometer or clock have some arrangement by which the 60th or other second may be detected when examining the tape. In some cases where the tape is marked by a stylographic pen, a second signal is given immediately

after it, or the pen is made to diverge from the normal line for a much longer period than for the other seconds. In the Hydrographic Office chronographs, the seconds record is made on the tape by a needle prick at each second, *excepting* at the 60th, which is omitted, so that its position is readily seen. In addition to this, an extra record is made immediately after the 30th second. It will be seen that it is imperative to have some particular second recorded from which the seconds signals may be counted. It is part of the duty of the assistant to see that one of these marked seconds occurs in the set of observations for each star, and against it must be recorded the hour and minute of the chronometer which it represents.

The key, or "Tapper," as it is called, for recording the observations, should have only a very light spring for keeping the contacts apart, and the same key should always be used, as, once an observer becomes accustomed to a particular key, a change to another would probably affect that observer's personal equation.

In reading off the tapes, it has been found convenient to run over the tape first, marking the pricks with a sharp pencil, numbering the seconds where they are required, and drawing a short line from the tapper signal at right angles to the length of the paper, and so transpose its position to the line of the clock dots. The tape will now be off the reel, and it can be read off, in the order in which it was used, as it is wound up ready for stowing away.

CHAPTER VI.

REDUCTION OF THE OBSERVATIONS.

The working out of the transits is done on Form No. 277 (R. O. Greenwich) *See* Appendix II. The methods of obtaining the various corrections are explained as follows in the order in which they are applied.

Enter the Number (or Letter) of transit used, date, name of observer, &c., at the top, and the names of the stars observed, one to each column. At the same time write in the position of R. A. Mic. East or West, and the reading at which the micrometer was set during the observations.

Next write against the wires the times as recorded on the chronograph placing a dash—against any wire missed.

Look in the ephemeris (NA.BJ. or CT.) for the star, and enter its declination (to the nearest minute for clock stars, but to seconds for polars) and R.A. (accurately to hundredths of a second) on the lines for these. Also the Sec. δ and Tan. δ (δ = declination) which are given in the NA and CT, but for stars from BJ these have to be looked out in a table of natural functions.

Take the sum and mean of the times of the wires as in any ordinary observations.*

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* A convenient way of taking the mean of the times on 9 wires is to add the units and tenths of seconds only, and divide by 9. Because the mean will, of course, be approximately the same as the 5th wire, add to the quotient just obtained such a number, the decimal place figures being the same as the unit figure, that will bring it nearest to the seconds of the time of the 5th wire, and the result will be the mean of the 9 times. Thus if the seconds and tenths of the observed times on the 9 wires are

$42^s{\cdot}6 \quad 45^s{\cdot}7 \quad 48^s{\cdot}6 \quad 51^s{\cdot}8 \quad 56^s{\cdot}9 \quad 2^s{\cdot}0 \quad 5^s{\cdot}0 \quad 8^s{\cdot}2 \quad 11^s{\cdot}0$

$9\,)41^s{\cdot}8 = $ Sum of 9 wires

$4{\cdot}64$

5th wire $= 56^s{\cdot}9$ therefore add $52{\cdot}22$

Mean $= 56{\cdot}86$

If the 5th wire had been about 58^s, we should have added 53·33.
If the 5th wire had been about 59, we should have added 54·44.

Correction to Central wire.—Once a good determination has been obtained, this correction remains constant so long as the wires are unbroken on the diaphragm. It is found in two ways.

The first, by the Nadir observation, gives the correction only for a full transit. It is made as follows*: (It should be remembered, that when using the Bohnenberger eyepiece, the reflected wires are reversed, and that the first wire reflected will be under the 9th direct, similarly the 2nd under the 8th, the 3rd under the 7th, the 4th under the 6th, and only the 5th or centre wire under its direct image). Now bring the 9th reflected and 1st direct wires tangential on both sides and put down the micrometer readings corresponding to these, then do this with the reflected and direct 5th or centre wire; next bring the 8th reflected and 2nd direct wires tangential, and put down the micrometer readings, and then repeat the observation with the 5th or centre wire; similarly with the 7th reflected and 3rd direct and 6th reflected and 4th direct, and so on, but placing the readings of the 1st reflected and 9th direct under those of the 9th reflected and 1st direct, those of the 2nd reflected and 8th direct under those of the 8th reflected and 2nd direct, &c., and mean up each set.

Reverse the instrument and repeat.

Now take the mean of these different sets, giving half weight to the 5th wire, and take the difference between this mean and the 5th wire mean. Multiply the difference by the value in seconds of time of one revolution of the micrometer screw, and the result is the correction to the middle wire for a full transit. Similarly with the observations with the instrument in the reversed position, and the mean of these results will be the final result by this method. If the mean readings of the different sets is greater than 5th wire mean, then the correction will be $-^{ve}$, but if less it will be $+^{ve}$.

NOTE.—The wires are usually numbered I. to IX. in the order from left to right as they appear in the diagonal eyepiece when the R. A. micrometer is West.

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*See note by Sir W. H. M. Christie, Monthly Notices, R.A.S., Fol. LXVII., p. 185.

Example :

	R. A. Micrometer West.			R. A. Micrometer East.	
I. & IX.	12·026	V or mid. wire	11·981	12·047	12·002
	11·954		11·940	11·989	11·959
IX. & I.	12·047		11·975	12·072	12 003
	11·984		11·933	12·013	11·962
Mean	12·0028		11·9573	12·0302	11·9815
II. & VIII.	11·983		11·979	12·017	12·007
	11·922		11·927	11·958	11·962
VIII. & II.	12·002		11·981	12·030	12·004
	11·946		11·928	11·980	11·966
	11·9632		11·9538	11·9962	11·9848
III. & VII.	11·989		11·981	12·012	12·006
	11·922		11·931	11·958	11·962
VII. & III.	11·988		11·980	12·015	12·007
	11·942		11·939	11·972	11·963
	11·9602		11·9578	11·9892	11·9845
IV. & VI.	11·976		11·981	12·002	12·003
	11·927		11·932	11·958	11·961
VI. & IV.	11·984		11·978	12·007	12·003
	11·938		11·931	11·964	11·959
	11·9562		11·9555	11·9828	11·9815
		Final mean of 5th wire	= 11·9561		11·9831

12·0028 × 2 = 24·0056
11·9632 × 2 = 23·9264
11·9602 × 2 = 23·9204
11·9562 × 2 = 23·9124
11·9561 × 1 = 11·9561
9) 107·7209
11·9690
11·9561

12·0302 × 2 = 24·0604
11·9962 × 2 = 23·9924
11·9892 × 2 = 23·9784
11·9828 × 2 = 23·9656
11·9831 × 1 = 11·9831
9) 107·9799
11·9978
11·9831

·0129 × 3^{s}·756 = 0^{s}·048
0 ·055
0 ·052 Mean Value adopted.

·0147 × 3^{s}·756 = 0^{s}·055

The other method is by taking a large number of Clock stars (full transit only) R. A. micrometer West, and taking the differences between the times of each wire and the mean wire for each. Put these on a form with a column for each wire, and a column for the Sec. δ of each star used. For convenience, divide these up into groups of 10, and mean each column in each group. Now divide the mean of each column by the mean of the Sec. δ column, and the result is the distance of each wire from the mean wire. Take the mean of all the groups.

Do the same thing with R. A. micrometer East, but, as the wires are reversed, the results must be reversed, to agree with the R. A. micrometer West results.

Now, what is required, is the distance in time from any wire to the middle or 5th wire. The distance between the middle wire and the mean is therefore subtracted from all the quantities just found, and the result is the interval of each wire from the middle wire.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX
	+	+	+	+	+	−	−	−	−
West	$13^s\cdot87$	$11^s\cdot31$	$8^s\cdot30$	$5^s\cdot27$	$0^s\cdot05$	$5^s\cdot21$	$8^s\cdot24$	$11^s\cdot27$	$14^s\cdot09$
East (reversed) ...	13 ·92	11 ·29	8 ·23	5 ·25	0 ·05	5 ·16	8 ·18	11 ·33	14 ·09
Intvls. from 5th wire — West	13 ·82	11 ·26	8 ·25	5 ·22	0 ·0	5 ·26	8 ·29	11 ·32	14 ·14
Intvls. from 5th wire — East	13 ·87	11 ·24	8 ·18	5 ·20	0 ·0	5 ·21	8 ·23	11 ·38	14 ·14
Accepted intervals	13 ·85	11 ·25	8 ·22	5 ·21	0 ·0	5 ·24	8 ·26	11 ·35	14 ·14

+ 38·53 − 38·99

To find the correction to the time of a transit as given by the mean of all nine wires, add the + intervals and the − intervals as above and take their difference (or algebraic sum of all the intervals) and divide by the

number of the wires, and the result after being multiplied by the Sec. δ for any particular star will be the correction to apply to a full transit.

$$\begin{array}{r} -\ 38{\cdot}99 \\ +\ 38{\cdot}53 \\ \hline 9)\ {\cdot}46 \end{array}$$

$$-\ 0{\cdot}051 \times \text{Sec. } \delta$$

The mean between this value, $-\ 0{\cdot}051$, and the correction obtained from the Nadir observation, as before explained, may be adopted as the correction used for all stars whose full transits have been observed.

This correction is multiplied by Sec. δ for each star.

In case of incomplete transits, the correction has to be calculated from the adopted wire intervals by taking the algebraic sum of all the wire intervals on which the star has been observed, and dividing by the number of wires; *the result* $\times$ *Sec.* δ *is the correction applied to the star.*

Thus supposing that a star had been observed on 1, 3, 4, 5, 7, 9 wires (Micrometer West)

	$0^{s}{\cdot}00$
$+\ 13^{s}{\cdot}85$	$-\ 8{\cdot}26$
$+\ 8{\cdot}22$	$-\ 14{\cdot}14$
$+\ 5{\cdot}21$	
$+\ 27{\cdot}28$	$-\ 22{\cdot}40$
	$+\ 27{\cdot}28$
	$6)+\ 4{\cdot}88$

$$0{\cdot}81 \times \text{Sec. } \delta$$

will be the correction to apply to the observed transit.

Note.—In this correction, care must be taken to remember that when stars are observed R.A.M. East, the wires, and, therefore, the intervals to be used, will be exactly reversed: that is, for the full transit, the sign will be reversed, and for an incomplete transit, the apparent first wire is really the ninth.

This correction applied to the "Mean" gives "Observed Transit."

Diurnal Aberration is applied at the same time as the Collimation Correction. This error is supposed to be caused by the rays of light striking a rapidly moving body as the Earth, and causing apparent deflection in the same way that rain will be apparently deflected when walking against it. This amount varies with the latitude as the equator travels at a greater speed than parallels nearer the Pole. The correction for a place in Lat. ϕ is $0^s{\cdot}021 \times$ Cos. ϕ. This is multiplied by Sec. δ, where δ is declination of star. It is always $-$ (minus) except for S.P. stars.

Collimation Error.—The phrase "line of collimation" has been explained in a previous chapter, and from principles there set down it may be inferred that its position can be found by setting the instrument alternately in the two positions Micrometer West and Micrometer East and setting the middle Micrometer wire accurately on the mark in each position. The mark may be the Nadir point, which is the point we look at when we make the middle wire coincide with the reflected image, it may be an actual mark such as a church steeple in the landscape, or it may be a slowly moving star near the Pole which by an artifice is treated as fixed, or finally it may be several quick moving stars from observations of which in the two positions of the instrument the position of the line of collimation may be deduced. It may happen that this position as shown by the reading of the R. A. Mic. may be different in the four cases. As stated in the earlier chapter, this may be the result of imperfectly shaped pivots or bearings, or it has been suggested that the differences are due to the different methods of illumination or of focus, which cause a shift of the apparent position of the wires. It seems worth while mentioning that, on this hypothesis of a lateral movement of the apparent wire, the line of collimation deduced from reversal observations on a mark of any kind is *the same line in the telescope in all cases* if the position of the apparent wire is the same before and after reversal, *even* though the reading of the micrometer is different *owing to this apparent wire being different in different methods.* For this reason it is advisable to keep focus and illumination the same before and after reversal. In actual

practice, as we are about to explain, some reading of the R.A. Micrometer is adopted from observations of various kinds as giving the line of collimation, but the position of this line which is actually used when the mean of results in two positions is finally taken, is that given by reversal on the clock stars.

Correction for Collimation.—To get this correction, take all the mean Nadir readings, two or more, obtained on the night and take the mean of them. This is called the adopted mean.

Take the difference between this adopted mean and the setting of the micrometer screw, and multiply this by the value in time of one revolution of the micrometer screw.

If the adopted reading is greater than the setting of the micrometer screw, provided the screw is right-handed, the correction is — for stars observed with R. A. Mic. West and + for stars observed with R. A. Mic. East. The reverse of this with S. P. stars.

This correction multiplied by the Sec. δ is applied to the "observed Transit."

To obtain the Collimation error from Polar Observations.—This only refers to Polars which have been taken by means of the micrometer screw and observed both ways, W. and E., for method, see page 47. Take the half difference between the observed transits W. and E., divide this half difference by the value of one revolution of the micrometer screw for that star. This is the collimation error in revolutions of screw, and can be turned into arc or time. If W. time is larger than E. time collimation error is +, and the correction to stars observed in the position Mic. West is —, with S.P. stars this is reversed.

Example taken from Appendix:

$53^s{\cdot}64$ E.
$50{\cdot}17$ W.

$3{\cdot}47$

Value of 1 rev$^{n.}$ = $63^s{\cdot}66$ $1{\cdot}735$

$\therefore$ Collimation = $\cdot 0272$ rev.

To obtain the collimation correction from the fixed mark.—Collimation can be found by means of a distant meridian mark without any adaptation, but if the mark be near, a collimating lens is necessary, which is placed in front of the telescope at such a distance that the mark is exactly in the focus of the lens and is seen clearly, the rays coming into the telescope parallel. At Greenwich, the mark is formed by a fine hole made in a piece of tin or zinc with a small needle, and a lamp placed at the back of it, and the whole fixed on the wall opposite and South of the instrument, at such a height, that, when the telescope is horizontal, the spot of light coming through the hole, is in the centre of the field, and appears like a star of about 2nd magnitude. The micrometer screw is now moved, and four bisections of this spot made with the middle wire, and read off. The instrument is then reversed, and six bisections made, after which it is again reversed and four more bisections made, thus :—

W.	E.	W.
12·313	11·672	12·322
·322	·680	·320
·339	·690	·323
·323	·683	·325
	·690	
97	·672	10
		12·3225
12·3242	7	·3242
	11·6812	12·3234
	12·3234	
Adopted mean.	12·0023	

mean up these results and mean the 1st and 3rd and the mean of this and the 2nd as in the above example. This is the adopted mean reading, and is treated similarly to the micrometer reading as found by the Nadir experiment above.

At times all three methods are used, and a mean value from the results adopted for the night's observations.

n tan δ.—The quantities *m* and *n* are the combination of the level and azimuth errors.

To find *n*. Take form 279 (see Appendix V.), fill in date, sidereal time and position of instrument. In column 4, enter (1) the name of a Polar star observed, and (2) that of a Clock star, selected so that its transit is as near as possible, in time, to that of the polar, and also so that the difference of the two tan δ will be as large as possible.

In column 5, put down the tan δ of the two stars under one another with their proper signs + or −. If the polar is S. P., then the sign is reversed. In column 6, put the R.A.—t for each star from form 277. This is an approximation to the clock error so far as the calculation has gone (difference between "Tabular apparent R. A." and "Sum.") If clock is slow, *t* is smaller than R.A., and therefore this R.A.—t will be +.

Take the algebraic difference of the two tan δ, and also of the two R.A.—t, and place them in their columns.

Divide the latter by the former, or the result of column 6 by that of column 5, and the quotient is *n* in seconds of time.

Repeat this process for all the polar stars observed during the night.

For adopted *n*, take the simple mean of all observed E., and also that of all observed W., and the mean of these results will be the adopted *n*. The signs must be carefully noted.

Returning now to Form 277, multiply *n* by the tan δ for each star, and apply the result to the "Sum." In doing this the sign of tan δ must be borne in mind, remembering that S.P. stars change the sign of their tan δ.

m is applied direct to the "Sum" without being multiplied by either sec. or tan δ.

To find *m* first find the *level error* in time using form 278. See Appendix IV. Fill in date, position of instrument, E. or W., and position of cross level, e or w.

In taking levels, an equal number of levels should be taken E. and W., and they should be spread out as evenly as possible through the observations, and also they

should be taken alternately e. and w. as previously stated.
w. e.
e. w.

Enter the micrometer readings for each observation, the readings of the E. and W. end of the bubble, and the mean bubble readings, in their respective columns.

Next take the mean of the two micrometer readings, first and last, whichever it may be, e. or w., and take the difference between that and the middle reading thus :—

e 11·0
w 13.0 > 10·5 = − 2·5
e 10·0

Put this result on the left side of column "differences," marking + if the *e* reading is greater, and − if *w* is greater.

Next take the mean of the first and last "mean bubble" readings, and take the difference between that and the middle one, and place the result on the right of column "differences," marking it + if the *w* reading is greater.

Now one division of the micrometer screw is known (of level *d* it is 0″·98). Also the values of the divisions of the level at different positions of the bubble are also ascertained by *calibration of level* see page 46.

Multiply the difference of micrometer readings by the value of one division of micrometer screw, and place result in column "In arc."

Multiply the difference of bubble readings by the value of one division of bubble at about the mean position of bubble, and place the result under the last figures in the "In arc" column.

Take *half* the algebraic sum, and place the result in the next column.

Proceed in the same manner for all the levels observed during the night's work.

Next take the Nadir readings, of which at least two will have been taken, one at the beginning, and one at the end of the observations. Place the E mean reading under the W mean reading for each observation, and take the difference. Multiply this difference by the

value of one revolution of R.A. micrometer screw (for transit D = 56″·34). Half this amount will be the level error by Nadir.

Example :

1st Nadir Obsⁿ.		2nd Nadir Obsⁿ.	
W. =	12·0079		12·0062
E. =	11·9409		11·9544
	·0670 × 56″·34		·0518 × 56″·34
	= 3″·774		= 2·918
Level Error =	1·887 +		= 1·459 +

If the W. reading is the greater the sign is +.

It is as well now to tabulate the resulting level errors on another form as shown—

Date. 1907.	Striding level.		Nadir.	Striding level Means.		Nadir Means.	Adopted level	
	W.	E.		W.	E.		In arc.	In time.
Sept. 19	+1″·65	+0″·99	+1″·887					
,,	+1 ·70	+1 ·00					*	
,,	+1 ·58	+0 ·41	+1 ·459	+1″·643	+0″·800	+1″ 673	+1″·402	0ˢ·093

* There are three observations of level, both ways, by striding level and two observations by Nadir ; give double value to the Nadir results :—

1·643 × 3 = 4·929
0·800 × 3 = 2·400
1·673 × 4 = 6·692

10) 14·021

1·402

To get the adopted level in arc, it is usual to give twice the value to a Nadir Observation as to a striding level E. or W.

Next rule out a form for the computation of m, and also of the Azimuth error.

Date. 1907.	Level error in time $= l$.	$l \times$ Sec. Lat.	n	n Tan.Lat.	m $= l$ Sec. Lat. $- n$ Tan. Lat.	Azimuth $= l$ Tan. Lat. $- n$ Sec. Lat.
1	2	3	4	5	6	7
Sept. 19	$+0^s{\cdot}093$	$+0^s{\cdot}150$	$+0^s{\cdot}184$	$+0^s{\cdot}231$	$-0^s{\cdot}081$	$-0^s{\cdot}179$

NOTE.—Remember that in S. lat. (being $-$ instead of $+$), the tan. lat. will be $-$, and will change the sign of *n tan lat.*

Fill in columns 1, 2, 4 from the above calculations. For column 3, multiply the level error in seconds of time by the natural secant of the lat., and for column 5, multiply "n" by the natural tangent of the latitude. m = Column 3 $-$ Column 5 noting the proper sign.

n tan δ and m are applied with their proper signs, in Form 277, and the result is the corrected clock time of the transit. The difference between this and the tabulated R.A. is the clock error.

To adjust the instrument in Azimuth.—Having set the instrument approximately in the meridian and made and reduced some observations as above described, the Azimuth Error, or the angle through which the instrument should be turned on the horizontal plane to make the great circle described by the line of collimation

pass through the North and South points of the horizon can be computed from the formula given on page 45. The instrument can be accurately adjusted *i.e.*, turned through this angle by means of the South meridian mark and the R.A. Micrometer screw.

If the sign of A is $+$, it indicates that a South Star transits too soon, and that the western pivot is too far south. In the case of the instrument we are describing, when the micrometer head is on the west side, if its reading be increased the wire frame in the eye-piece is moved in the direction opposite to that of a South Star's motion, or eastward. Therefore, if we first bisect the South mark with the middle wire, then increase the reading by a quantity equivalent to the angle through which the instrument is to be turned, and finally move the stand by the Azimuth Adjusting Screw until the mark is again bisected by the middle wire, the instrument will have been moved through the requisite angle.

Obviously, if A is found to be negative, the reading of the R.A. Mic. must be decreased after the mark has been first bisected.

Also if the meridian mark is North, the reading must be decreased for a positive value of A, and *vice versa*.

CALIBRATING THE LEVEL.

Place the level in position on the instrument and adjust by the cross level.

Turn the micrometer screw until the bubble is towards one end of the run, and set the screw to an even division.

Read both ends of bubble, and take the mean and difference of these readings. The mean is the position of the centre of the bubble, the difference is the length of the bubble.

Turn the micrometer screw two divisions and repeat, and continue this for the whole length of the level tube, and then work back in the same

way. The entries in the book will now be somewhat as follows :—

Micrometer Reading.	East End of Bubble.	West End of Bubble.	Mean.	Difference.
d.	d.	d.	d.	d.
8·0	9·0	64·5	36·75	55·5
10·0	10·5	66·3	38·40	55·8
12·0	11·4	67·2	39·30	55·8
14·0	12·9	68·8	40·85	55·9
&c.	&c.	&c.	&c.	&c.

Now taking the column of "means," the difference between any two consecutive readings is equal to 2 divisions of the micrometer screw which is known. Take the first two :—

$$\begin{array}{r} 36{\cdot}75 \\ 38{\cdot}40 \\ \hline 1{\cdot}65 \end{array} = 2 \text{ divisions of micrometer screw} = 2 \times 0''{\cdot}98 = 1''{\cdot}96.$$

Therefore 1 division of the bubble $= \dfrac{1''{\cdot}96}{1{\cdot}65} = 1''{\cdot}188$ with a bubble of 55·7 divisions length and with its centre at 37·57 divisions. Similarly the other values can be calculated, and after several sets of observations have been obtained mean values are given and adopted. For this purpose plotting the values on a curve is most useful as the division values can then be seen at a glance without interpolation as required with a table.

OBSERVING POLARS USING MICROMETER SCREW.

Polar stars, especially the slower moving ones with declinations above 85°, may be observed by means of the R.A. micrometer screw, and a great deal of time thereby saved. To do this take off the cover of the screw and

turn the head until the centre wire is just in front of the star, and then wait for it to pass under the wire and when it is bisected press the key of the chronograph and read off the micrometer screw reading. Repeat this for 10 bisections. It is very often convenient to observe both E. and W. in this manner, commencing the observations in time to obtain the first ten before the star is on the meridian, and then reversing and getting the second ten observations when it is just past, but of course, as soon as possible after the first set. From observations of the same polar E. and W. the collimation error can be found. (See page 40.)

To reduce the above (See Appendix III.) Take the difference between each of the micrometer readings and the adopted setting for the night. Now multiply the value of 1 revolution of micrometer screw in seconds of time by the sec. δ for the star and the result will be the value of 1 revolution of the screw for that value of δ. Now multiply each of the above differences by this value and the result will be the amount in seconds of time to be added to or subtracted from each of the corresponding times to reduce it to the transit over the centre wire at the adopted setting for the night. These results should not differ more than 5 seconds for a star about 3° from the pole, for closer stars possibly more, and if carefully observed will not differ more than about 2 seconds. Take the mean of all these results and this will be the "observed transit" which is then corrected for collimation, &c., &c., as usual.

The observations given in the Appendix have been taken, as they were observed, from observations made on one night, August 7th, 1908.

On this occasion the 9th wire, west, had broken and it will be noticed that for this reason the stars have been observed on eight wires only. This will illustrate the kind of accident which may at any time happen. In this case it shows how, having obtained a good value for the wire intervals, these eight wires may be reduced to the central wire as previously explained.

It not unfrequently happens, that, especially on nights with fast flying clouds, the star under observation

will be only visible occasionally during its motion from the first to the last wire, and perhaps a few only of the wires (as in this sense the transits are usually termed) are obtained. It need hardly be said that, other things being equal, the fewer the number of wires over which a star has been observed the smaller will be the value given to the result obtained from it.

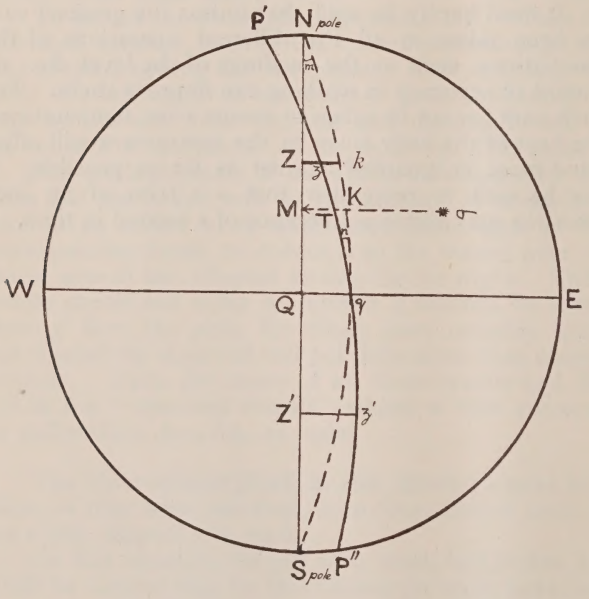
It will be noticed that the results obtained from the east and west observations differ by an approximately constant amount which is repeated in the Polar observations. This may be due to an imperfect determination of collimation error as before explained.

It need hardly be said that unless the greatest care has been taken in all the different operations of the observations, such as the readings of the level, &c., no amount of accuracy in working can improve them. Too much care cannot be taken to ensure even temperatures. The heat of the body close to the instrument will affect it and must be guarded against as far as possible. It may be well to remember that a 1/1000 of an inch distortion may cause a difference of a second in time.

Appendix I.

On the quantities m and n used in the reduction of transit observations.—

The diagram represents the projection of the celestial sphere of a place in some given longitude, but latitude not yet defined, on a plane at right angles to the equator and meridian.



The north and south celestial poles are in this plane, *i.e.*, the plane of the paper. The line N.Q.S. represents the meridian and W.Q.E. the equator.

Suppose a transit instrument at this place, not perfectly adjusted in the meridian, so that its line of collimation describes the great circle P′ *q* P″ cutting the

equator in q. Through the true north and south poles and the point q describe a great circle N q S.

Suppose a star σ moving from east to west and crossing the meridian at M.

The sidereal time when it reaches M. is its right ascension = R A.

The time actually recorded is the time by the clock when it crosses the apparent meridian of the instrument, the great circle P′ q P″, at T = t.

The angle Q N q (or Q S q) = m.

The angle P′ q N (or P″ q S) = n.

To find the right ascension from the observed time t must be corrected by—

(1) The amount the clock is slow = C.

(2) The time the star takes to traverse the arc T M = (M K − T K).*

Now the length of T K = n sin. q K, and the time taken by the star σ to pass over T K = $\frac{n \text{ sin. } q \text{ K}}{\text{sin. N K}}$ = $n \frac{\text{sin. } q \text{ K}}{\text{cos. } q \text{ K}}$ = n tan. δ where δ is the declination of σ.

∴ The time of transit of σ over the true meridian = t + C + m − n tan. δ.

If the position of the instrument had been such that P′ had been to the east of N the quantity n tan. δ would have to be added, and, adopting the usual convention that n and m are to be considered + when the corresponding corrections have to be added, the general formula may be written :—

$$\text{R A} = t + \text{C} + n \text{ tan. } \delta + m.$$

To find n :

Choose two stars widely separated in declination whose declinations are δ_1 and δ_2, let R A_1 and R A_2 be

* It must be remembered that the time that a star takes to traverse an arc of given length varies inversely as the sine. of its north polar distance, and that in a triangle such as M N K, nearly isosceles and having the vertical angle (m) small, the base M K = vertical angle × sin. N M (or N K). It follows from this that the time a star of any declination whatever takes to pass from the great circle N q S to the true meridian is m (the angle Q N q measured in seconds of time).

their respective right ascensions, and their observed times of transit over the apparent meridian of the instrument t_1 and t_2. Then from the above formula :—

$$\text{R A}_1 - t_1 = \text{C} + n \text{ tan. } \delta_1 + m.$$
$$\text{R A}_2 - t_2 = \text{C} + n \text{ tan. } \delta_2 + m.$$

and $(\text{R A}_1 - t_1) - (\text{R A}_2 - t_2) = n \text{ (tan. } \delta_1 - \text{tan. } \delta_2).$

The quantity m is found by observations of the level.

If Z be the true zenith of the place of observation, and Z z k be an arc of the prime vertical, so that z is the apparent zenith of the instrument, Z z will be the measured level error = L.

$$Z\ k = Z z + z\ k = \text{L} + (z\ q\ k \times \text{sin. } q\ k).$$

Also $Z\ k = \text{Z N } k \times \text{sin. N } k = m \text{ sin. N } Z.$

But $q\ k = Z\ \text{Q} = \lambda$ and N $Z = 90 - \lambda$ where λ = latitude of the place.

$\therefore$ m cos. $\lambda = \text{L} + n$ sin. λ and $m = \text{L sec. } \lambda + n \text{ tan } \lambda.$

In the figure as drawn it must be noted that n is negative and therefore the general formula for m will be written :—

$$m = \text{L sec. } \lambda - n \text{ tan } \lambda.$$

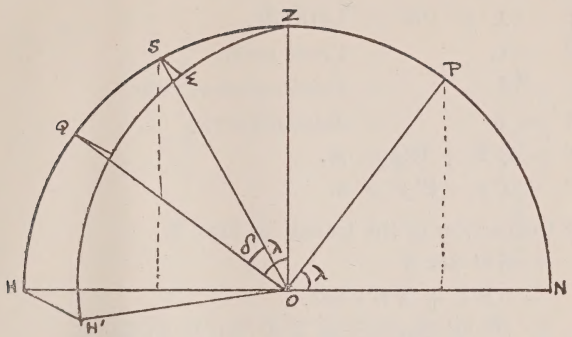
It is obvious from consideration of the diagram that :

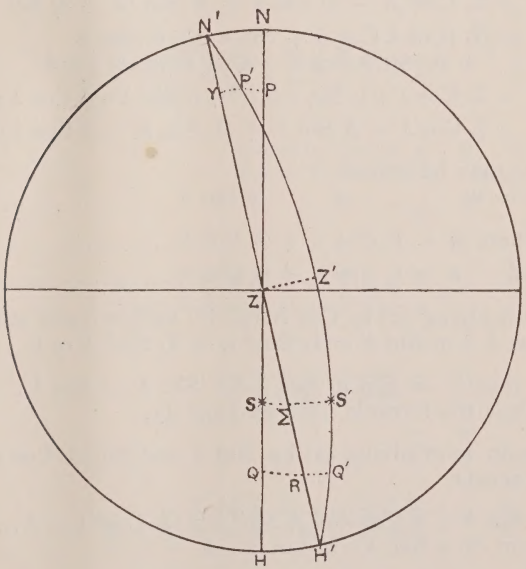
(1) The correction for n has a different sign for stars north or south of the equator, which is provided for by the factor tan. δ which has a negative sign (−) when δ is south.

(2) If the place of observation is south of the equator the zenith will be in a position as Z', in which case the above formula for computing m is $Z\ k = \text{L} - z\ q\ k$ sin. $q\ k$. It must therefore be remembered in computing m that when south of the equator tan λ will be negative.

(3) In a place on the equator m is simply the determined level error. In this case, or in places near the equator, the azimuth is of comparatively little account as the clock stars observed are near the celestial equator and therefore near the zenith.

The algebraical connection between n and m and the azimuth and level errors of the instrument is shown on the next page.





This diagram is a projection of the celestial sphere on the plane of the horizon, N′Z′H′ being the great circle described by the line of collimation of the displaced instrument, when $ZQ = \lambda = PN =$ latitude.

$ZQ = \lambda = PN =$ Latitude.
$ZZ' = L =$ Level error.
$SQ = \delta =$ Declination of Star.
$HH' = A =$ Azimuth error.
$QQ' = Q'R + RQ = m.$
$PP' = Py - P'y = n.$

The Correction to the transit of Star S

$= SS' \text{ Sec } \delta$
$= (S\Sigma + \Sigma S') \text{ Sec } \delta$
$= (H H' \text{ Sin } Z S + Z Z' \text{ Sin } H S) \text{ Sec } \delta$
$= \{A \text{ Sin } (\lambda - \delta) + L \text{ Cos } (\lambda - \delta)\} \text{ Sec } \delta$
$= L \text{ Cos } (\lambda - \delta) \text{ Sec } \delta + A \text{ Sin } (\lambda - \delta) \text{ Sec } \delta$
$= L (\text{Cos } \lambda \text{ Cos } \delta + \text{Sin } \lambda \text{ Sin } \delta) \text{ Sec } \delta$
$\quad + A (\text{Sin } \lambda \text{ Cos } \delta - \text{Cos } \lambda \text{ Sin } \delta) \text{ Sec } \delta$
$= L \text{ Cos } \lambda + L \text{ Sin } \lambda \tan \delta + A \text{ Sin } \lambda - A \text{ Cos } \lambda \tan \delta)$
$= L \text{ Cos } \lambda + A \text{ Sin } \lambda + (L \text{ Sin } \lambda - A \text{ Cos } \lambda) \tan \delta$

which may be written

$= m + n \tan \delta$

Where $m = L \text{ Cos } \lambda + A \text{ Sin } \lambda$ .....(*a*)
And $n = L \text{ Sin } \lambda - A \text{ Cos } \lambda$ .....(*b*)

Multiplying (*a*) by Cos λ and (*b*) by Sin λ and adding;
$m \text{ Cos } \lambda + n \text{ Sin } \lambda = L \text{ Cos}^2 \lambda + L \text{ Sin}^2 \lambda = L$ .....(*c*)

$\therefore m = (L - n \text{ Sin } \lambda) \text{ Sec } \lambda = L \text{ Sec } \lambda - n \tan \lambda$ .....(*d*)
which is the formula used on page 45.

Again multiplying (*a*) by Sin λ and (*b*) by Cos λ and subtracting

$m \text{ Sin } \lambda - n \text{ Cos } \lambda = A \text{ Sin}^2 \lambda + A \text{ Cos}^2 \lambda = A$.....(*e*)
or from (*b*) $n \text{ Sec } \lambda = L \tan \lambda - A$

$\therefore L \tan \lambda - n \text{ Sec } \lambda = A$ ..... (*f*)

From either of these two last formulæ the Azimuth error can be computed and the instrument adjusted in Azimuth as described on page 46.

ROYAL OBSERVATORY, GREENWICH. [FORM No. 277.]

Observations with Transit D. at Greenwich, 1908, August 7th. Observer, C.E.M.

Name of Star ... Ephemeris	β Ophiuchi N.A.			μ Herculis N.A.			89 Herculis N.A.			ν Ophiuchi N.A.		
Declination (δ)	4°37′ N.			27°47′ N.			26°4′ N.			9°46′ S.		
Sec. δ Tan δ	1·003		+0·081	1·130		+0·527	1·113		+0·489	1·015		−0·172
Position of Mic. and Reading	E. 11·990			E.			E.			E.		
	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.
Wire 1			—			—			—			—
2	17	39	3·0	17	42	58·0	17	51	49·5	17	54	4·7
3	*2·9		5·9	3·5		1·5	3·3		52·8	3·3		8·0
4	3·1		9·0	3·5		5·0	3·2		56·0	3·0		11·0
5	5·2		14·2	6·0		11·0	6·0		2·0	5·2		16·2
6	5·3		19·5	5·7		16·7	5·9		7·9	5·3		21·5
7	3·1		22·6	3·5		20·2	3·3		11·2	3·1		24·6
8	3·0		25·6	3·5		23·7	3·2		14·4	3·1		27·7
9	2·7		28·3	2·8		26·5	3·0		17·4	2·5		30·2
Sum			48·1			22·6			31·2			63·9
Mean			16·01			12·83			3·90			17·99
Corrⁿ. to Central Wire ...			− 1·72			− 1·94			− 1·91			− 1·74
Observed Transit	17	39	14·29			10·89			1·99			16·25
Corrⁿ for Diurnal aberration			− ·01			− ·01			− ·01			− ·01
,, ,, Collimation ...			+ ·02			+ ·02			+ ·02			+ ·02
Sum			14·30			10·90			2·00			16·26
n. tan. δ (*n* = − 1.ˢ489) ...			− ·12			− ·79			− ·73			+ ·26
m. ... (+1·7902)			+ 1·79			+ 1·79			+ 1·79			+ 1·79
Corrected Transit	17	39	15·97	17	42	11·90	17	52	3·06	17	54	18·31
Tabular Apparent R.A. ...	17	38	57·35	17	41	53·10	17	51	44·20	17	53	59·56
Clock apparently slow ...			−18·62			−18·80			−18·86			−18·75

* The figures in the left of each column are the differences between consecutive wires, taken for check.

ROYAL OBSERVATORY, GREENWICH. [FORM No. 277.]

Observations with Transit D. at Greenwich, 1908, August 7th. *Observer*, C.E.M.

Name of Star ... Ephemeris	67 Ophiuchi B.J.			η Serpentis N.A.			109 Herculis B.J.			α Lyræ N.A.			2 Aquilæ N.A.		
Declination (δ)	2°56′ N.			2°56′ S.			21°44′ N.			38°42′ N.			9°9′ S.		
Sec. δ Tan δ ...	1·001		+0·051	1·001		−0·051	1·077		+0·399	1·281		+0·801	1·013		−0·161
Position of Mic. and Reading	W. 11·990			W.			W.			W.			W.		
	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.
Wire 1	17	56	7·1	18	16	37·6	18	19	51·1	18	33	51·7	18	37	18·9
2	*2·6		9·7	2·7		40·3	2·7		53·8	3·4		55·1	2·4		21·3
3	3·0		12·7	3·1		43·4	3·2		57·0	3·8		58·9	3·3		24·6
4	2·9		15·6	3·0		46·4	3·3	20	00·3	3·7	34	02·6	3·0		27·6
5	5·2		20·8	5·3		51·7	5·7		06·0	6·7		09·3	5·4		33·0
6	5·3		26·1	5·1		56·8	5·6		11·6	6·7		16·0	5·4		38·4
7	2·9		29·0	3·0		59·8	3·2		14·8	3·8		19·8	2·8		41·2
8	3·3		32·3	3·0	17	2·8	3·1		17·9	4·1		23·9	3·2		44·4
9			—			—			—			—			—
Sum			73·3			78·8			32·5			57·3			9·4
Mean			19·16			49·85			4·06			7·16			31·18
Corr$^{n.}$ to Central Wire ...			+ 1·72			+ 1·72			+ 1·85			+ 2·20			+ 1·74
Observed Transit	17	56	20·88	18	16	51·57	18	19	5·91	18	34	9·36	18	37	32·92
Corr$^{n.}$ for diurnal abberr$^{n.}$ ...			− ·01			− ·01			− ·01			− ·02			− ·01
,, ,, Collimation ...			− ·02			− ·02			− ·02			− ·03			− ·02
Sum			20·85			51·54			5·88			9·31			32·89
n. tan. δ (n = − 1.^{s}489) ...			− ·08			+ ·08			− ·59			− 1·19			+ ·24
m. ... (+1·7902)			+ 1·79			+ 1·79			+ 1·79			+ 1·79			+ 1·79
Corrected Transit	17	56	22·56	18	16	53·41	18	19	7·08	18	34	9·91	18	37	34·92
Tabular Apparent R. A. ...	17	56	4·06	18	16	34·84	18	18	48·47	18	33	51·36	18	37	16·24
Clock apparently slow ...			−18·50			−18·57			−18·61			−18·55			−18·68

* The figures in the left of each column are the differences between consecutive wires, taken for check.

ROYAL OBSERVATORY, GREENWICH.

Observations with Transit D. at Greenwich, 1908, August 7th. Observer, C.E.M.

1	2	3	4	5	6	7	8	9
Name of Star	δ Ursæ Min. N.A.	Mic. Screw readings.	Difference of Mic. Screw readings and setting for night (11·990).	Log of Column 4.	Column 5 + const. log = log correction.	Correction in Seconds.	Correction.	Corrected times.
Declination (δ)	86° 37′ 4″ N.							
Sec. δ Tan δ	16·9501 +16·9206							
Position of Mic. & Reading	W. (11·990)							
	H. M. S.	r	r			s.		H. M. S.
Bisections 1...	17 59 59·1	14·688	2·698	0·43104	2·23494	171·8	+2 51·8	18 02 50·9
2...	00 31·2	14·163	2·173	·33706	2·14096	138·3	2 18·3	49·5
3...	01 06·5	13·618	1·628	·21165	2·01555	103·6	1 43·6	50·1
4...	30·8	13·236	1·246	·09552	1·89942	79·3	1 19·3	50·1
5...	55·1	12·853	0·863	$\bar{1}$·93601	1·73991	55·0	0 55·0	50·1
6...	2 17·6	12·501	0·511	$\bar{1}$·70842	1·51232	32·5	0 32·5	50·1
7...	48·6	12·018	0·028	$\bar{2}$·44716	0·25106	1·8	+0 1·8	50·4
8...	3 18·8	11·547	0·443	$\bar{1}$·64640	1·45030	28·2	−0 28·2	50·6
9...	41·0	11·196	0·794	$\bar{1}$·89982	1·70372	50·6	0 50·6	50·4
10...	4 00·2	10·880	1·110	0·04532	1·84922	70·7	1 10·7	49·5
Sum								1·7
Mean...								18 2 50·17
Observed Transit								18 2 50·17
Diurnal Aberration								− ·22
Corr^{n} for Collimation ...								− ·36
Sum = t								18 2 49·59
n. tan. δ (n = −1·489) ..								−25·19
m. ... (+1·7902)... ...								+ 1·79
Corrected Transit ...								18 2 26·19
Tabular Appar. R.A.								18 2 8·31
Difference ...								−17·88

1 rev. of Mic. Screw = 3·756^{s} = 0·5747256
Log. Sec. δ = 86·37·4 = 1·2291731
Const. log. = 1·8038987

Value of 1 rev. of Mic. Screw for δ Ursæ Minoris... ... } 63 ·66

EXAMPLE OF POLAR OBSERVED WITH MIC. SCREW. APPENDIX III.—*(continued)*.

ROYAL OBSERVATORY, GREENWICH.

Observations with Transit D. at Greenwich, 1908, August 7th. *Observer*, C.E.M.

1	2	3	4	5	6	7	8	9
Name of Star	δ Ursæ Minoris							
Declination (δ)	86° 37′ 4″ N.							
Sec. δ Tan δ	16·9501 +16·9206							
Position of Mic. & Reading	East (11·990)	Mic. Screw reading.	Difference between Mic. Screw reading and setting for night. (11·990).	Log of Column 4.	Column 5 + const. log = log correction.	Corrections in seconds.	Correction.	Corrected time.
	H. M. S.							H. M. S.
Bisection 1	18 5 54·8	14·841	2·851	0·45500	2·25890	181·5	−3 1·5	18 2 53·3
2	6 21·6	15·259	3·269	0·51441	2·31831	208·1	3 28·1	53·5
3	6 50·2	15·701	3·711	0·56949	2·37339	236·3	3 56·3	53·9
4	7 13·7	16·078	4·088	0·61151	2·41541	260·3	4 20·3	53·4
5	7 35·0	16·405	4·415	0·64493	2·44883	281·1	4 41·1	53·9
6	7 54·6	16·729	4·739	0·67569	2·47959	301·7	5 1·7	52·9
7	8 17·5	17·067	5·077	0·70561	2·50951	323·2	5 23·2	54·3
8	8 40·5	17·441	5·451	0·73648	2·54038	347·0	5 47·0	53·5
9	9 7·9	17·856	5·866	0·76834	2·57224	373·5	6 13·5	54·4
10	9 31·0	18.236	6·246	0·79560	2·59950	397·7	6 37·7	53·3
Sum								6·4
Mean...								18 2 53·64
Observed Transit								18 2 53·64
Diurnal aberration								− ·22
Corrⁿ for Collimation ...								+ ·36
Sum = *t*								18 2 53·78
n tan. δ (*n* = −1ˢ·489) ...								−25·19
m. ... (+1·7902)								+ 1·79
						Corrected Transit ...		18 2 30·38
						Tabular Appar. R.A.		18 2 8·31
						Difference ...		−22·07

[FORM No. 278.]

ROYAL OBSERVATORY, GREENWICH.

Level Error of Transit D. at Greenwich. *Observer.* C.E.M.

Date. Approx. Sidereal Time.	Position of Inst. and Altitude.	OBSERVATIONS. Cross level. Bubble length.	Mic. Reading.	Reading of Bubble. E.	W.	Mean.	DIFFERENCES. Mic. reading + if *e* is greater.	Bubble reading + if *w* is greater.	In arc.	Half Sum = Level.
1908							*r*	*d*	"	"
August 7th		48·6 w.	7·0	15·5	64·1	39·80			− 1·96	
17^h-45^m	E.	48·4 e.	7·0	16·2	17·3	42·00	− 2·0	− 1·12	− 1·68	− 1·820
		48·3 w.	11·0	17·8	66·1	41·95			− 3·64	
		48·7 e.	11·0	69·0	20·2	44·60			− 2·45	
18^h-22^m	W.	48·8 w.	13·0	19·5	68·2	43·85	− 2·5	− 0·22	− 0·30	− 1·375
		49·1 e.	10·0	68·1	19·0	43·55			− 2·75	
		49·6 w.	10·0	16·7	66·3	41·50			− 2·94	
19^h-23^m	E.	49·7 e.	7·0	66·5	16·8	41·65	− 3·0	− 0·07	− 0·11	− 1·525
		49·7 w.	10·0	16·8	66·5	41·65			− 3·05	
		50·2 w.	8·0	66·7	16·5	41·60			− 2·45	
19^h-55^m	E.	50·0 e.	5·0	16·0	66·0	41·00	− 2·5	+ 0·17	+ 0·26	− 1·095
		50·1 w.	7·0	65·8	15·7	40·75			− 2·19	
		50·4 e.	7·0	67·9	17·5	42·70			− 2·94	
20^h-18^m	W.	50·6 w.	10·0	17·1	67·7	42·40	− 3·0	− 0·10	− 0·17	− 1·555
		50·4 e.	7·0	67·5	17·1	42·30			− 3·11	
		50·7 w.	7·0	65·8	15·1	40·45			− 3·43	
20^h-55^m	E.	51·0 e.	4·0	15·8	66·8	41·30	− 3·5	− 0·25	− 0·38	− 1·905
		50·7 w.	8·0	67·0	16·3	41·65			− 3·81	

Observations with the Bohnenberger eyepiece.

At beginning of evening :—	*r*
West	11·9745
East	12·0170
Difference	0·0415
At end of evening :—	
West	11·9708
East	12·0201
Difference	0·0493

Level error deduced from the observations with Bohnenberger eyepiece.

"

(1) − 1·194

− 1·392

Level error adopted for the night.

"

− 1·35

= − 0·090

The Mean of the readings with the Bohnenberger eyepiece are ... ... *r* 11·9958, and *r* 11·9955

Level 1 rev. = 0″·98

[FORM No. 279.]

ROYAL OBSERVATORY, GREENWICH.

Computation of n. Transit D. at Greenwich. Observer, C.E.M.

Date.	Approx. Sidereal Time.	Pos^{n} of Ins.	Polar Star (1). Clock Star (2).	Tan. dec. (1). ,, ,, (2).	R.A.—t.	Quotient of differences = n.
				Difference (1)−(2).	Difference (1)−(2).	
	H. M.				M. S.	S.
1908 August 7th	18 2	W.	δ Ursæ Min.	+ 16·921	− 0 41·28	
	17 56		67 Ophiuchi	+ 0·051	− 0 16·79	
				+ 16·870	− 0 24·49	− 1·455
	18 8	E.	δ Ursæ Min.	+ 16·921	− 0 45·47	
	17 53		ν Ophiuchi	− 0·172	− 0 16·70	
				+ 17·093	− 28·77	− 1·682
	18 56	W.	Cephei 51 S.P.	− 20·388	+ 0 10·17	
	18 51		θ Serpentis	+ 0·071	− 0 17·14	
				− 20·459	+ 0 27·31	− 1·335
	19 2	E.	Cephei 51 S.P.	− 20·388	+ 0 17·60	
	19 20		δ Aquilæ	+ 0·051	− 0 17·90	
				− 20·439	+ 0 34·79	− 1·700
	19 45	E.	ε Draconis	+ 2·753	− 0 21·36	
	19 50		β Aquilæ	+ 0·108	− 0 17·21	
				+ 2·645	− 4·15	− 1·581
	20 5	W.	Groombridge 1119 S.P.	− 52·495	+ 0 50·67	
	20 12		α^{1} Capricorni	− 0·227	− 0 16·66	
				− 52·268	+ 67·33	− 1·288
	20 49	E.	76 Draconis	+ 7·293	− 0 28·33	
	20 42		ε Aquarii	− 0·173	− 0 17·02	
				+ 7·466	− 0 11·31	− 1·515
				Mean of the Values of *n* in West position		− 1·359
				,, ,, ,, ,, ,, East ,,		− 1·620
				Adopted *n*		− 1·489

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